

Recent Results from the STAR Experiment at RHIC

Nu Xu

Lawrence Berkeley National Laboratory

Many Thanks to the Organizers



Outline

1) Introduction

2) STAR Experiment at RHIC

- Status of the experiment
- Recent results on ***Conic Emissions***

3) Explore the QCD Phase Diagram

- Beam Energy Scan Program at RHIC

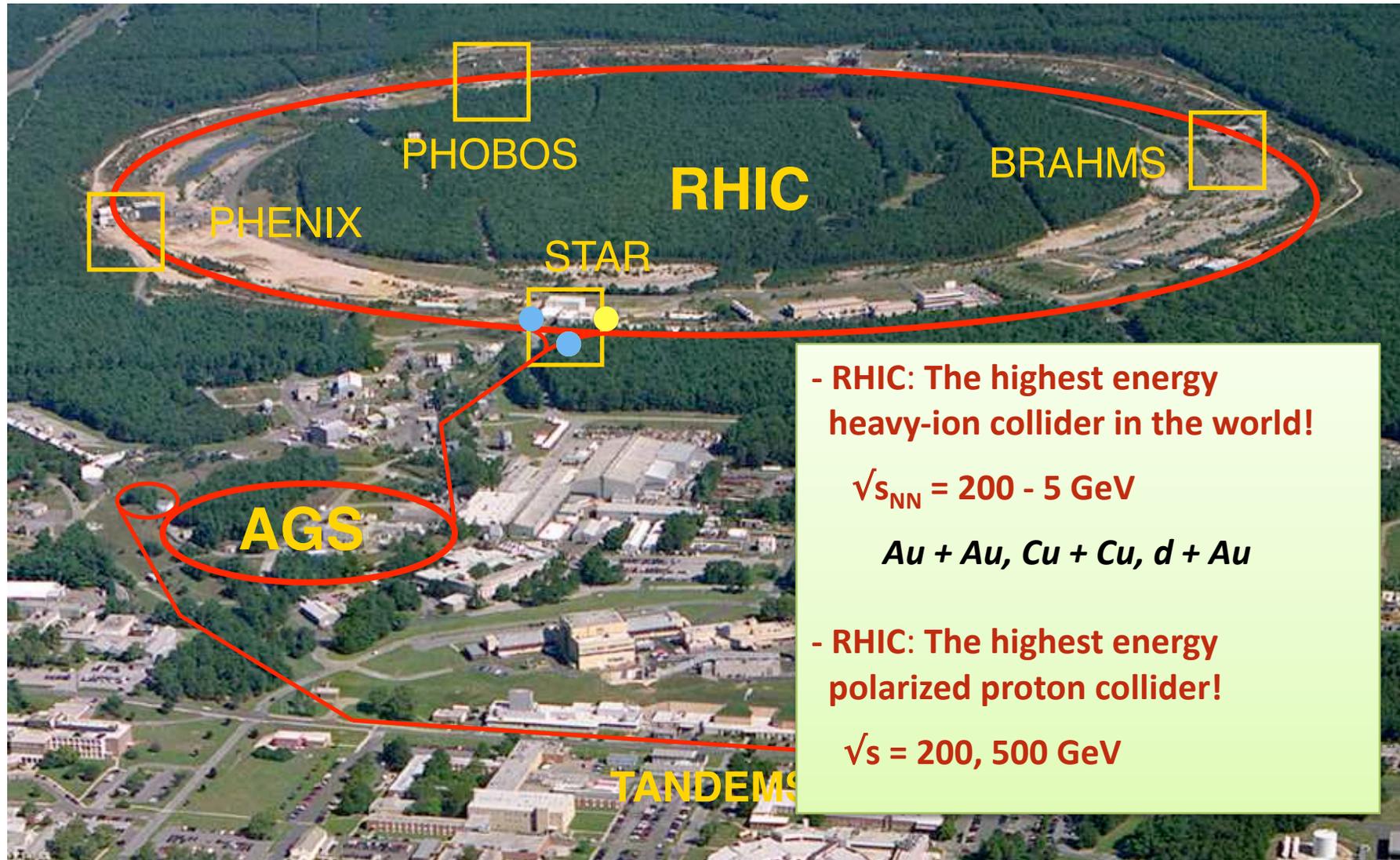


Physics Goals at RHIC

- Identify and study the properties of matter (EOS) with partonic degrees of freedom.
- Explore the QCD phase diagram.

Relativistic Heavy Ion Collider (RHIC)

Brookhaven National Laboratory (BNL), Upton, NY



- RHIC: The highest energy heavy-ion collider in the world!

$$\sqrt{s_{NN}} = 200 - 5 \text{ GeV}$$

Au + Au, Cu + Cu, d + Au

- RHIC: The highest energy polarized proton collider!

$$\sqrt{s} = 200, 500 \text{ GeV}$$

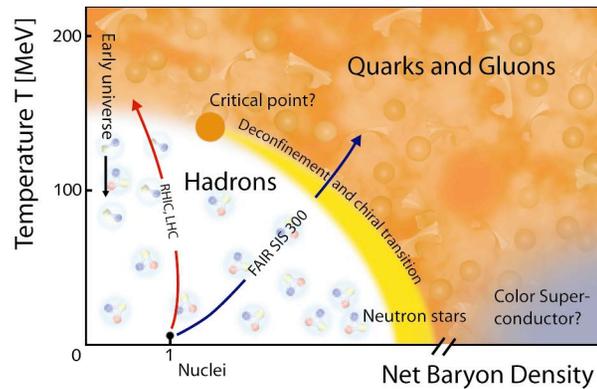
Animation M. Lisa



STAR Experiment



STAR Physics Focus

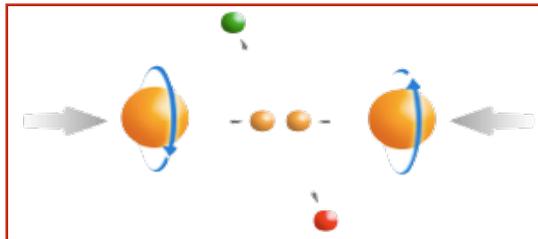


1) Heavy-ion program

- Study *medium properties, EoS*
- pQCD in hot and dense medium

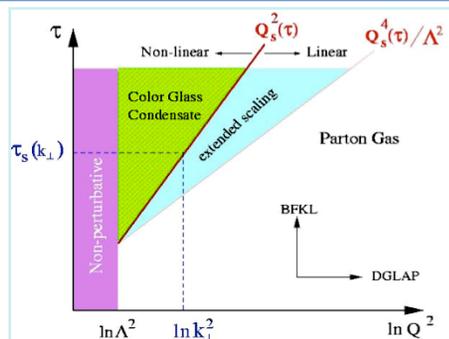
2) RHIC beam energy scan

- Search for *critical point*
- Chiral symmetry restoration



Polarized spin program

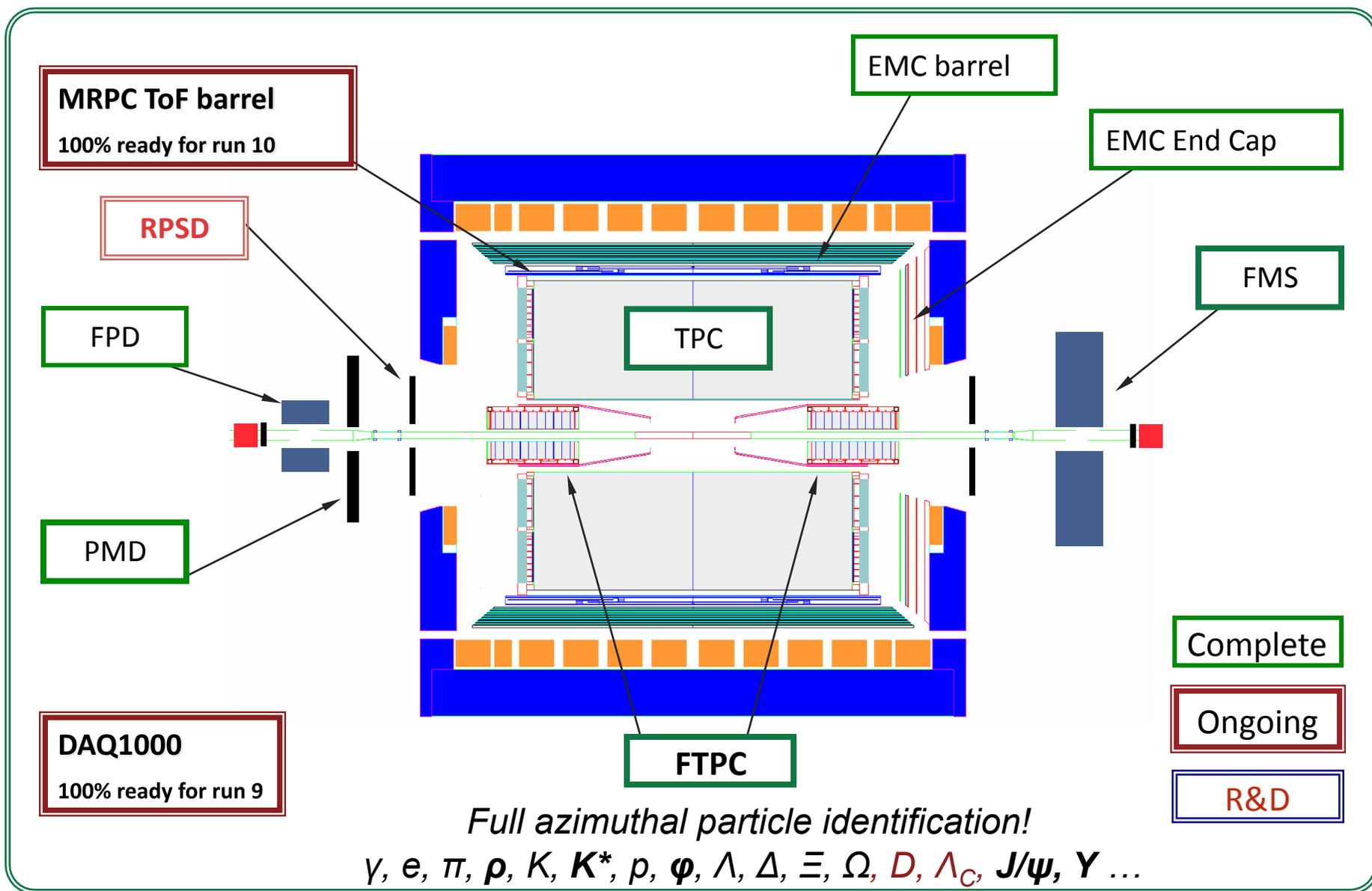
- Study *proton intrinsic properties*



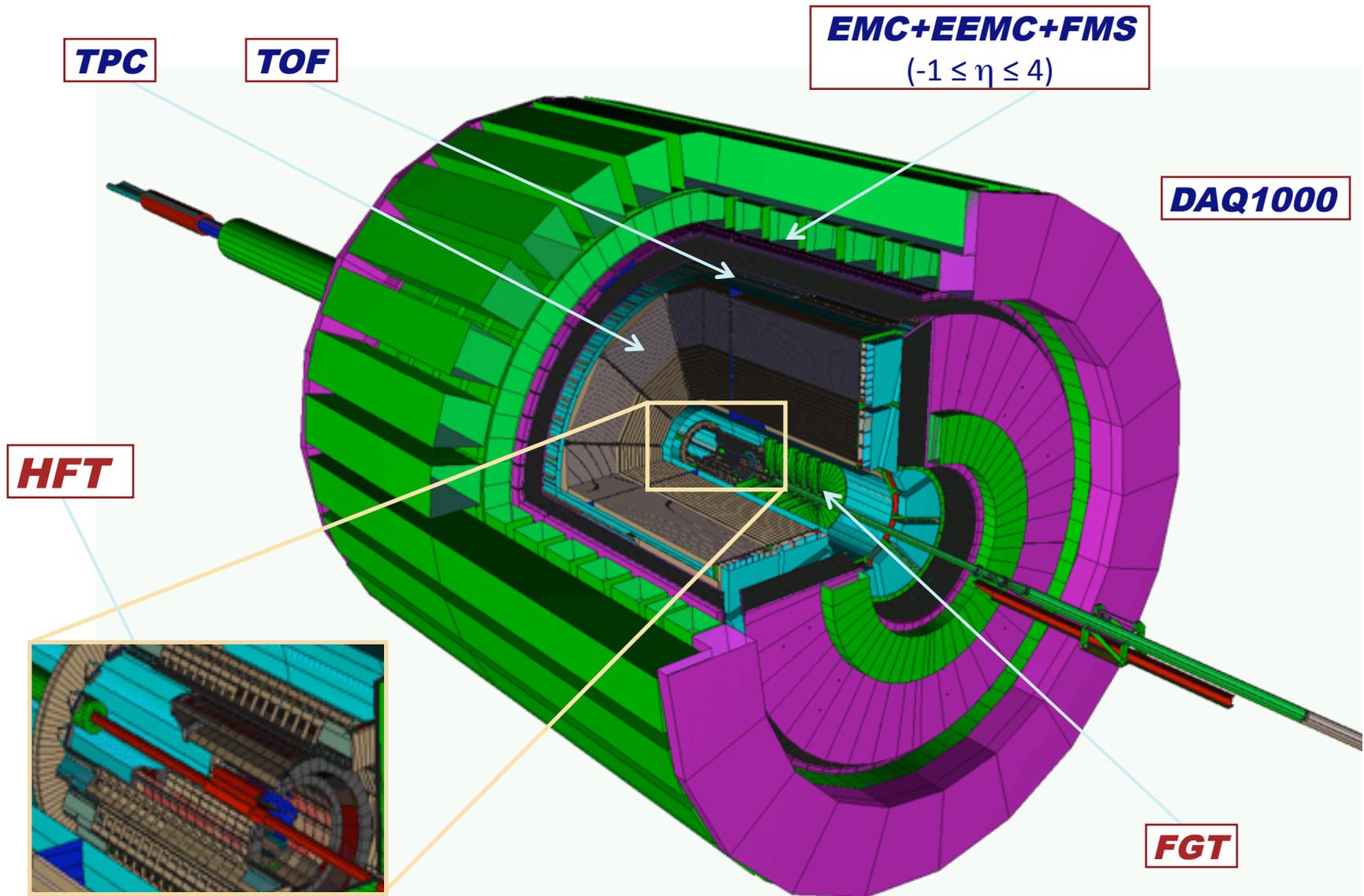
Forward program

- Study low-x properties, search for *CGC*
- Study elastic (inelastic) processes (pp2pp)
- Investigate *gluonic exchanges*

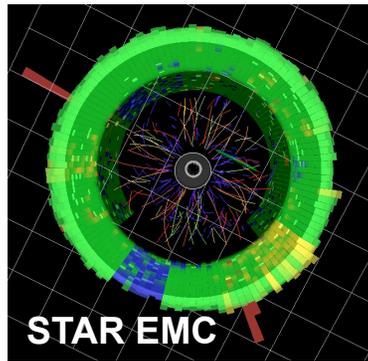
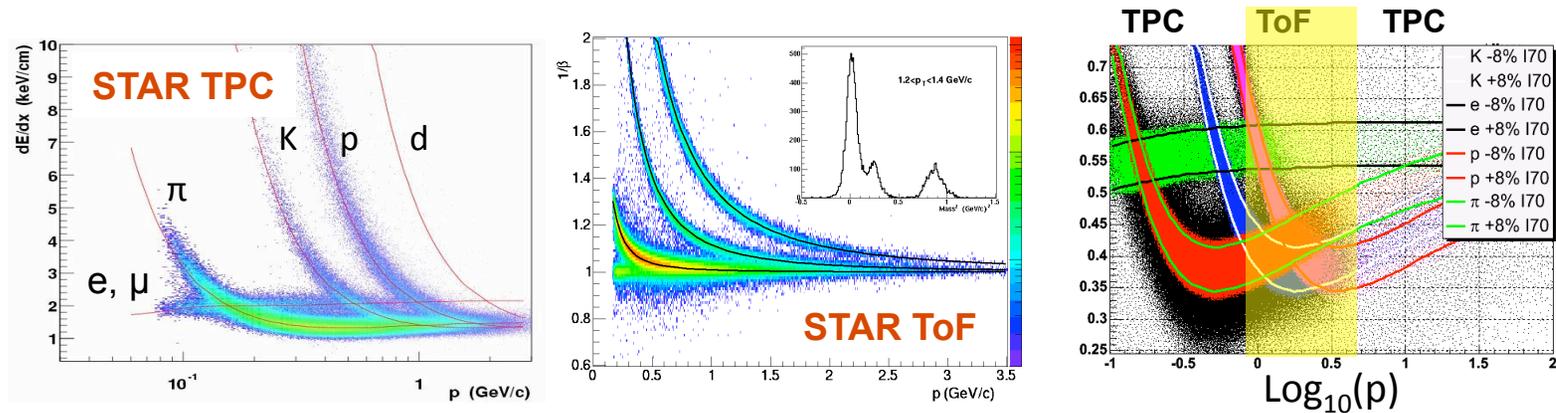
STAR Detector



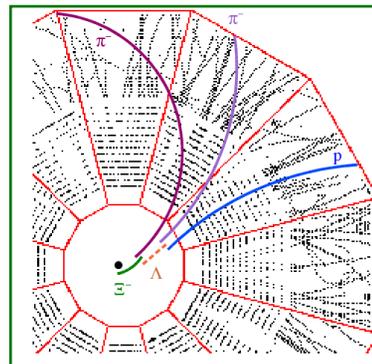
STAR Detectors: *Full 2π particle identification!*



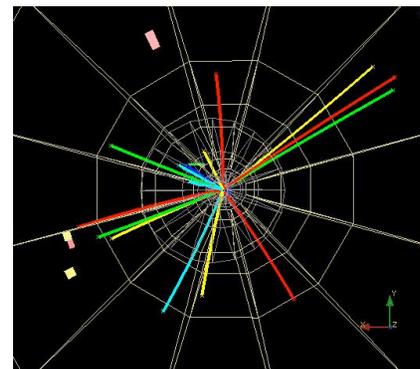
Particle Identification at STAR



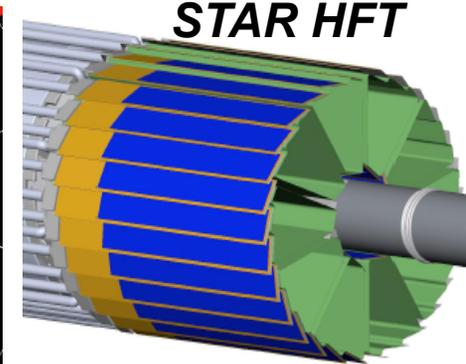
Neutral particles



Strange hyperons



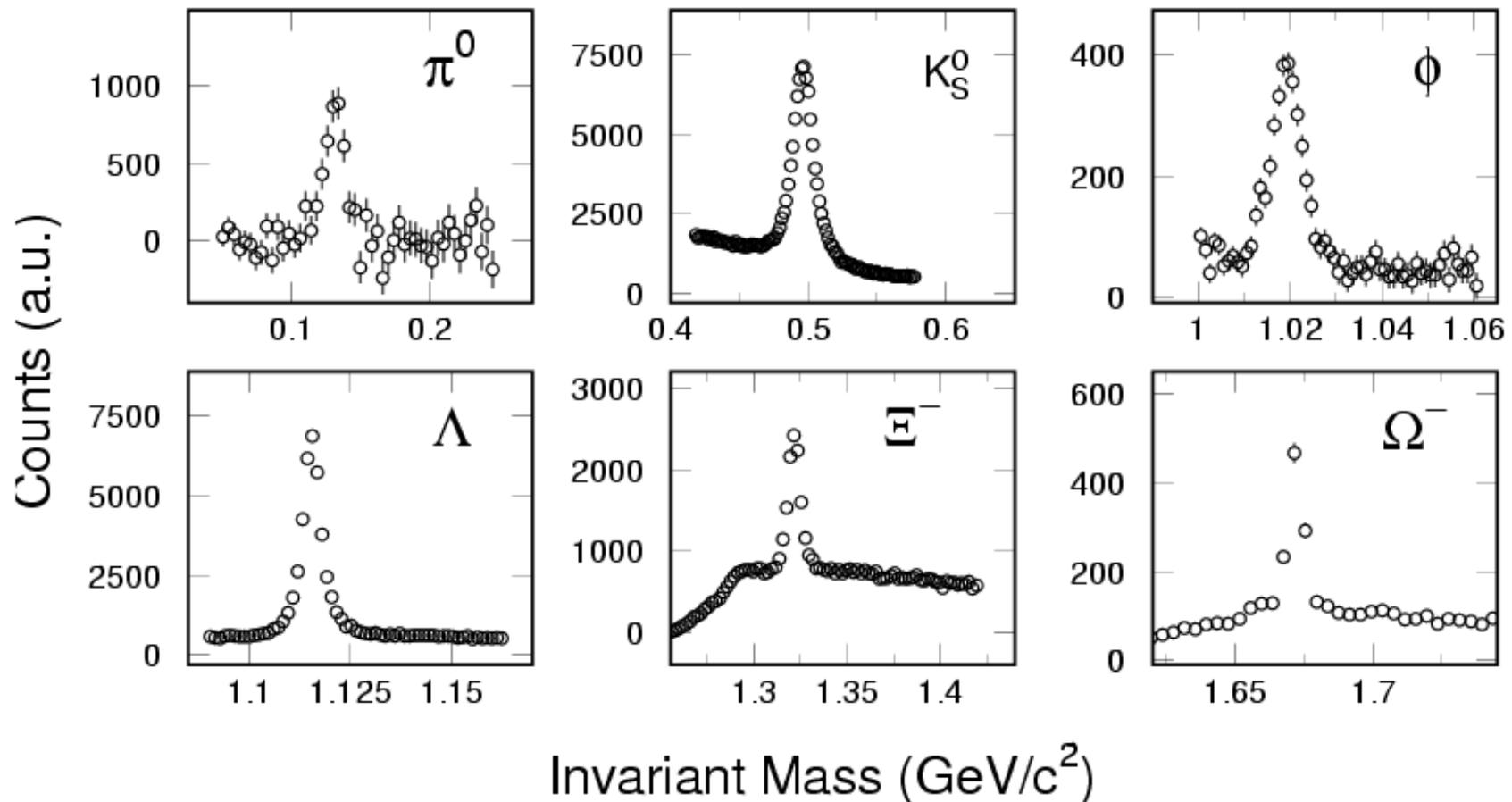
Jets



Heavy Quark Hadrons

Multiple-fold correlations among the identified particles!

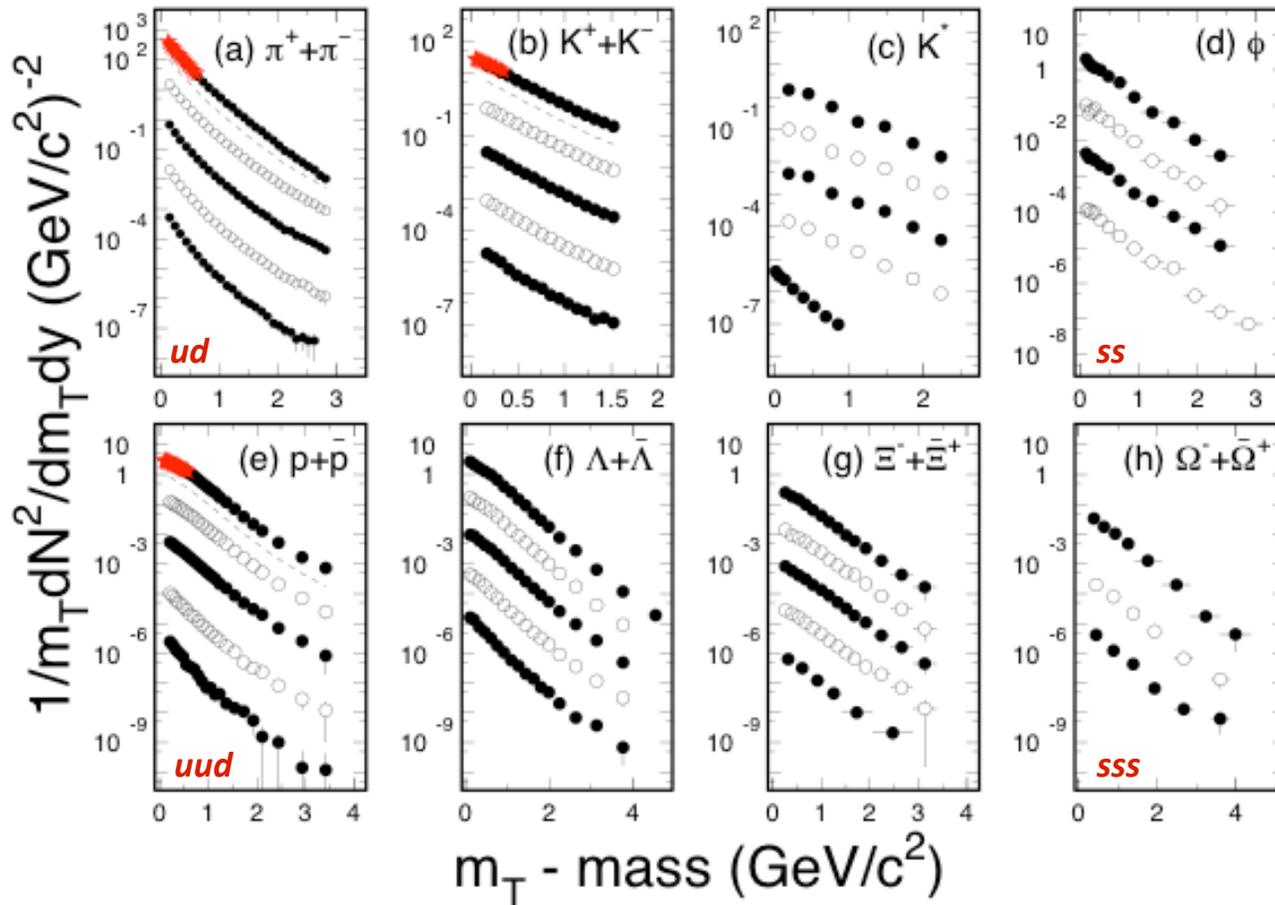
Particle Identification (ii)



Reconstruct particles in full azimuthal acceptance of STAR!

Hadron Spectra from RHIC

p+p and Au+Au collisions at 200 GeV



more central collisions
↑
0-5%

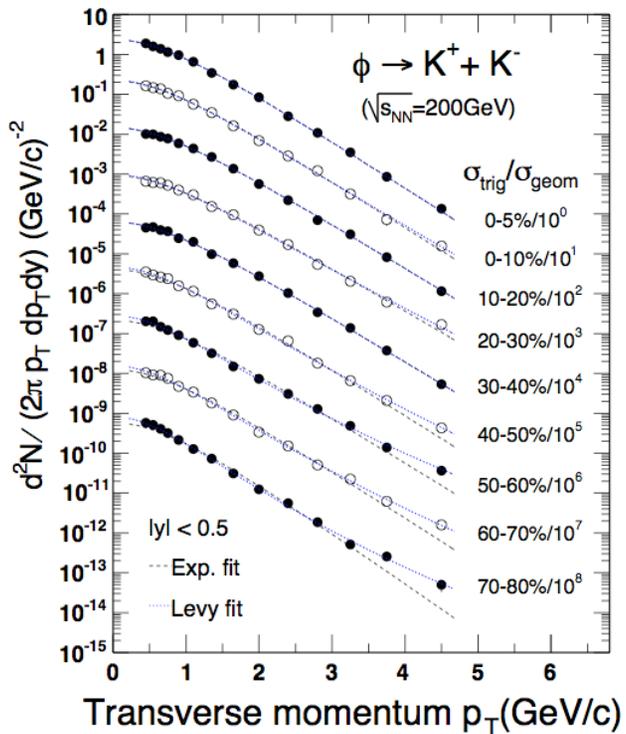
$$m_T = \sqrt{p_T^2 + m^2}$$

$$f \propto \exp(-m_T/T_{slope})$$

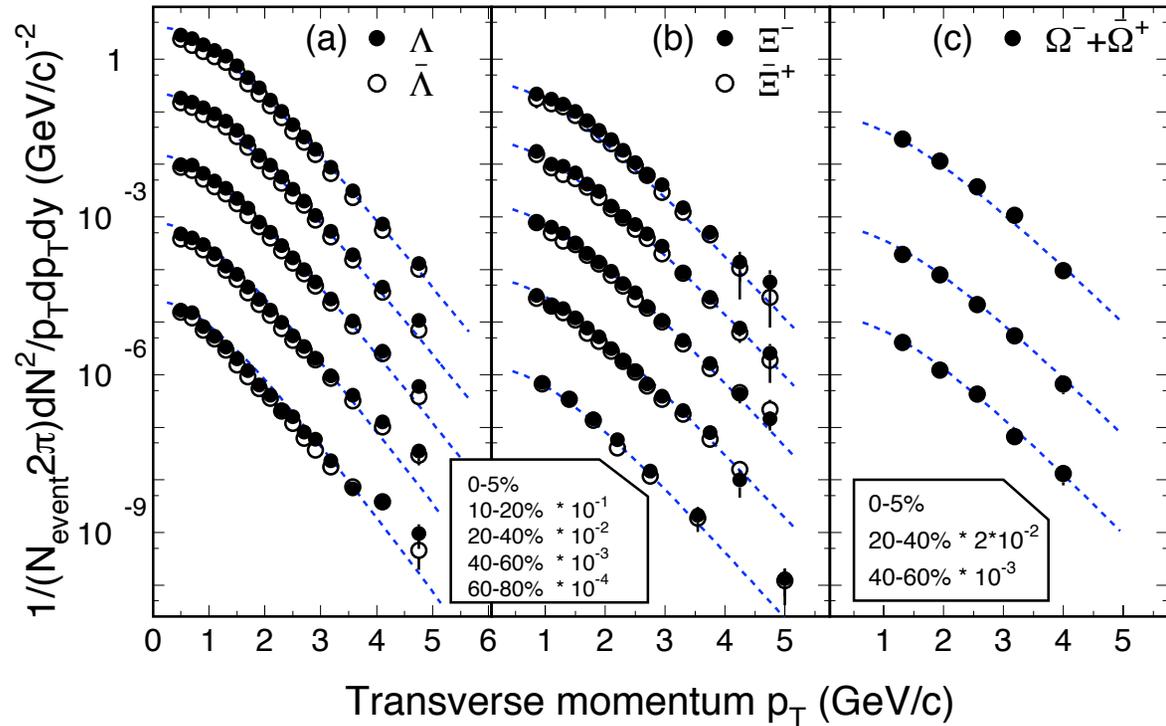
Multi-strange hadron spectra are exponential in shape.
 STAR white papers - Nucl. Phys. A757, 102(2005).

ϕ - mesons and Strange Baryons

STAR: PRL. 99 (2007) 112301



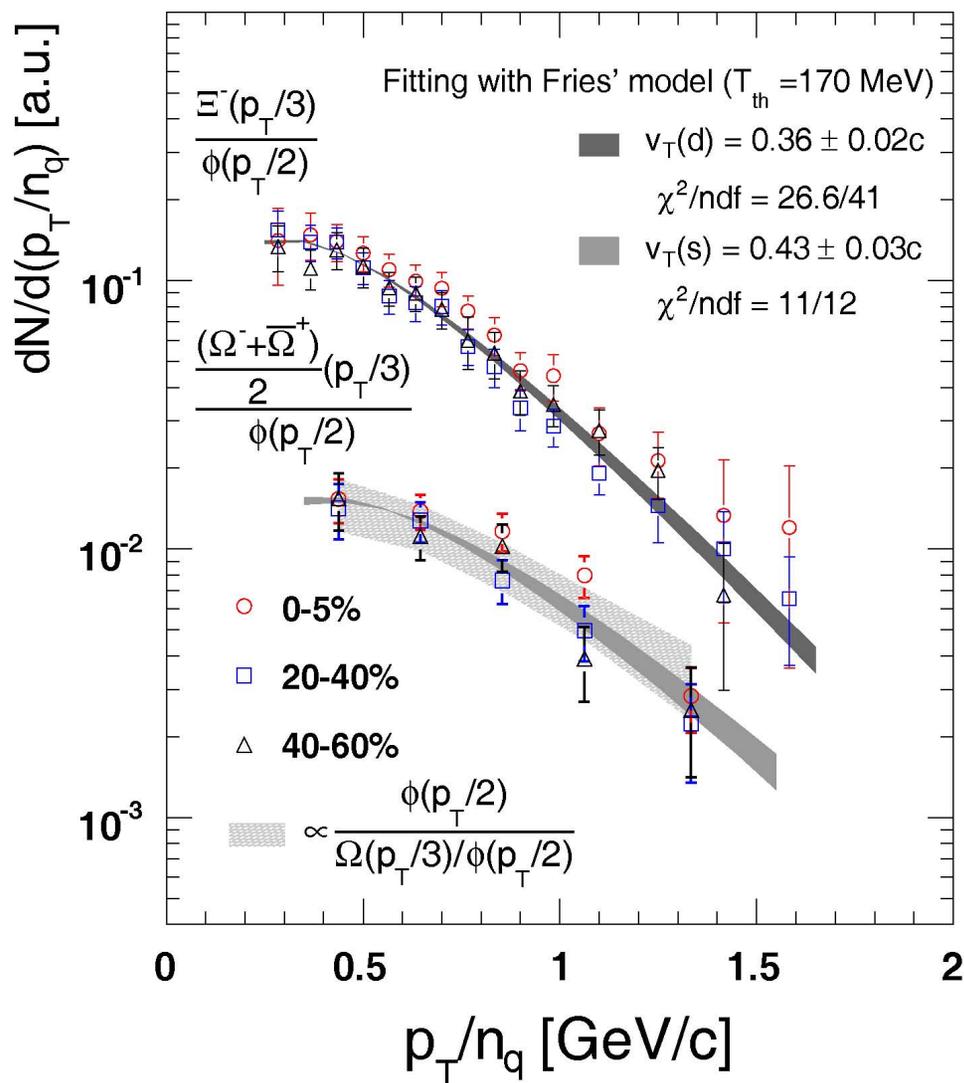
Phys. Rev. Lett. 98, 62301(2007)



ssbar fusion \Rightarrow ϕ -meson formation!

STAR: Phys. Lett. B612, 81(2005)

The s- and d-quark Spectra



$$s = \frac{\Xi(p_T / 3)}{\phi(p_T / 2)}$$

$$d = \frac{(\Xi^- + \Omega^+)(p_T / 3)}{2 \phi(p_T / 2)}$$

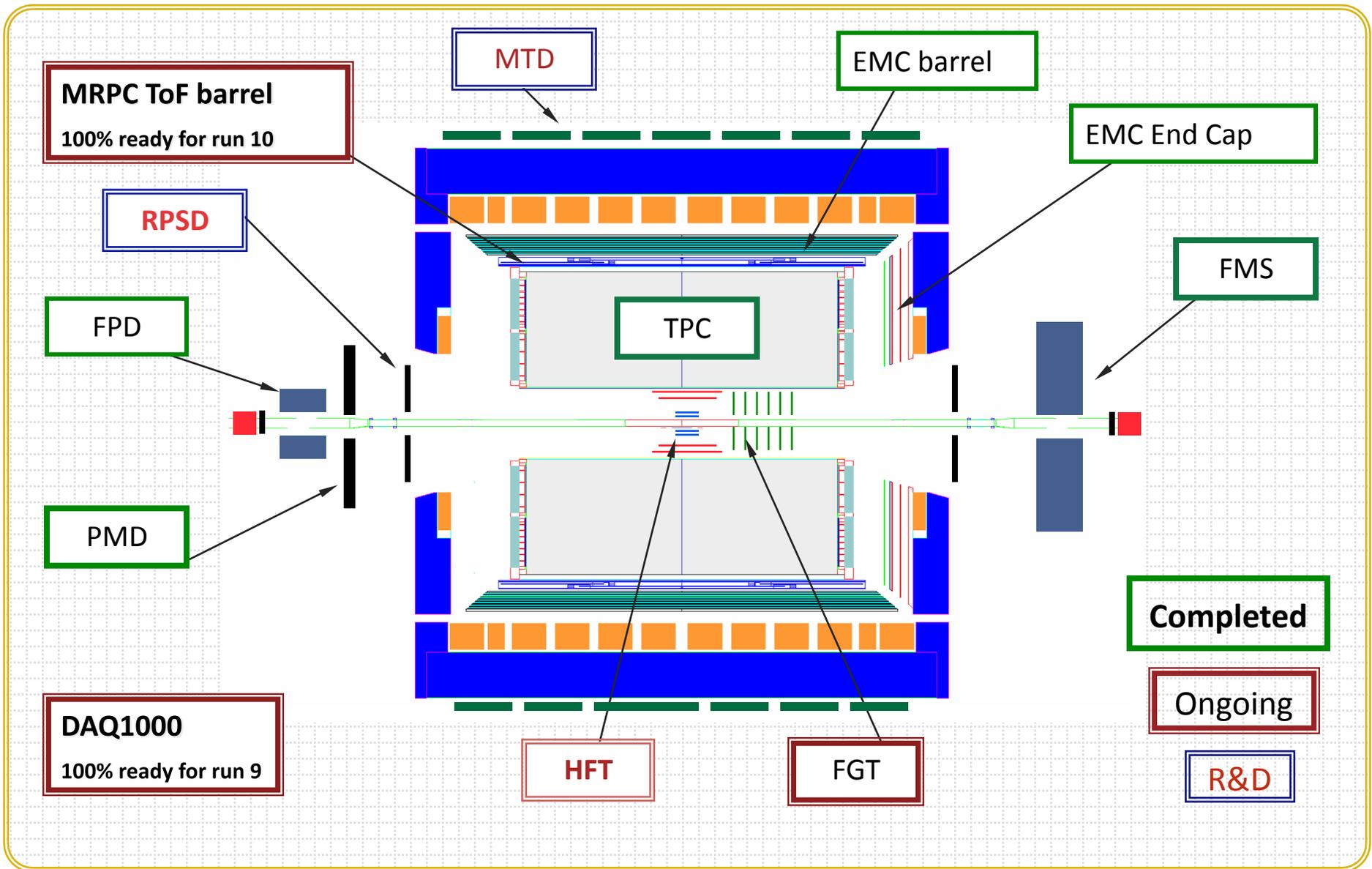
Assuming that the process of hadronization follows coalescence



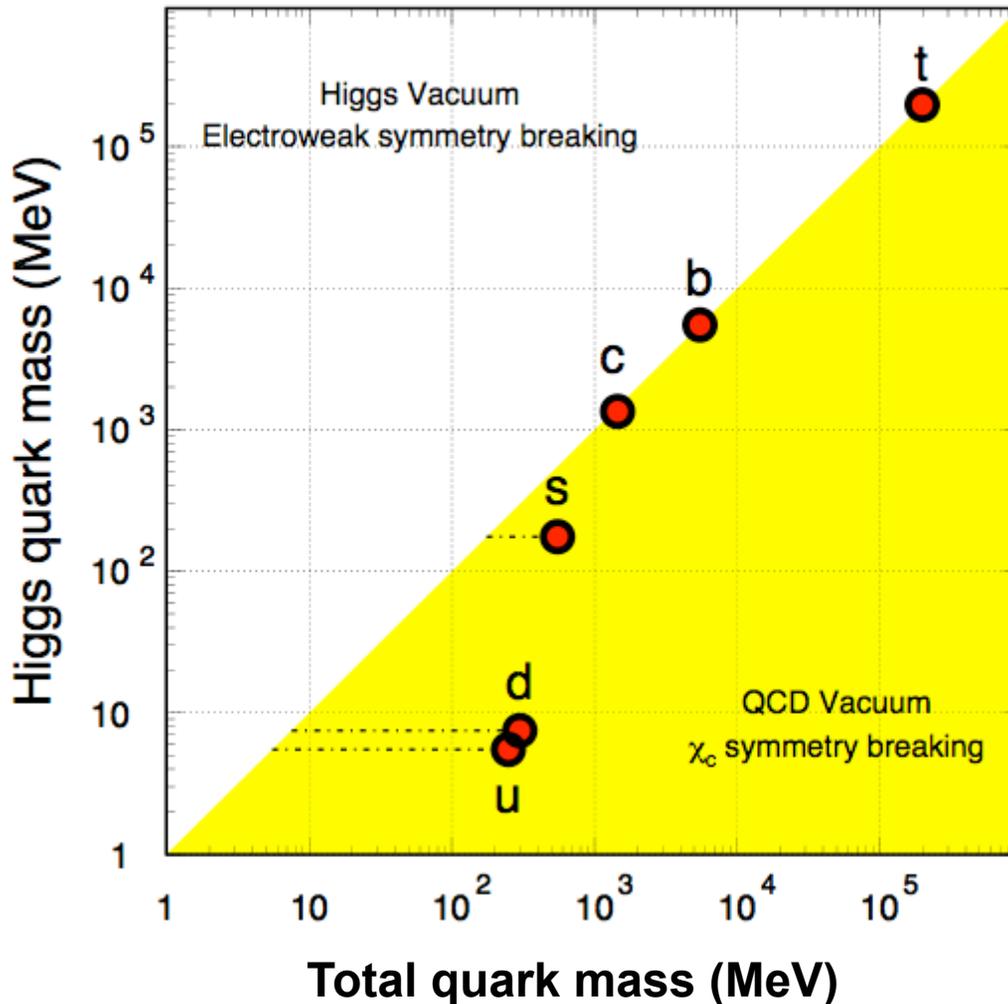
- parton spectra
- 'partonic collective flow' velocity $\sim 0.35-0.45 c$

JinHui Chen: SQM08
c.f. *Phys. Rev.* **C78** (2008) 034907

STAR Detector

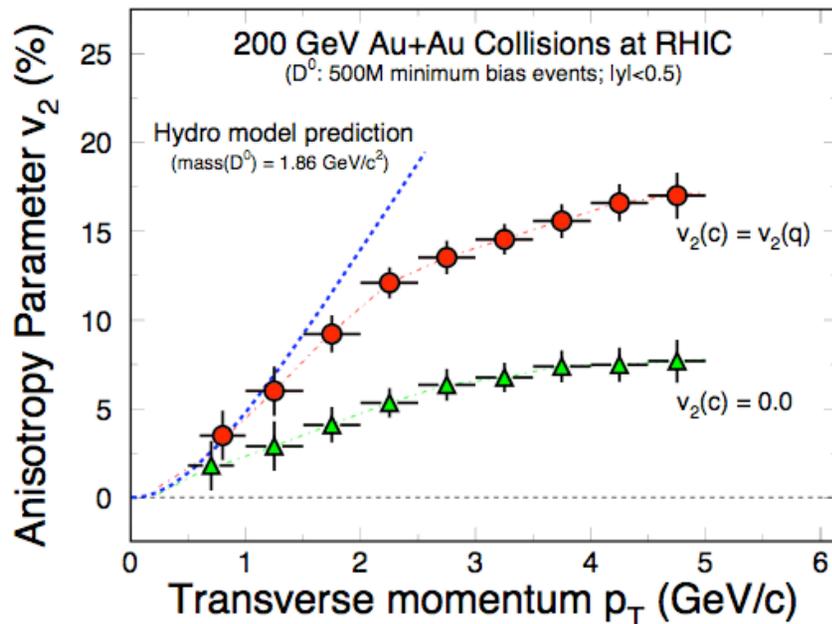


Quark Masses



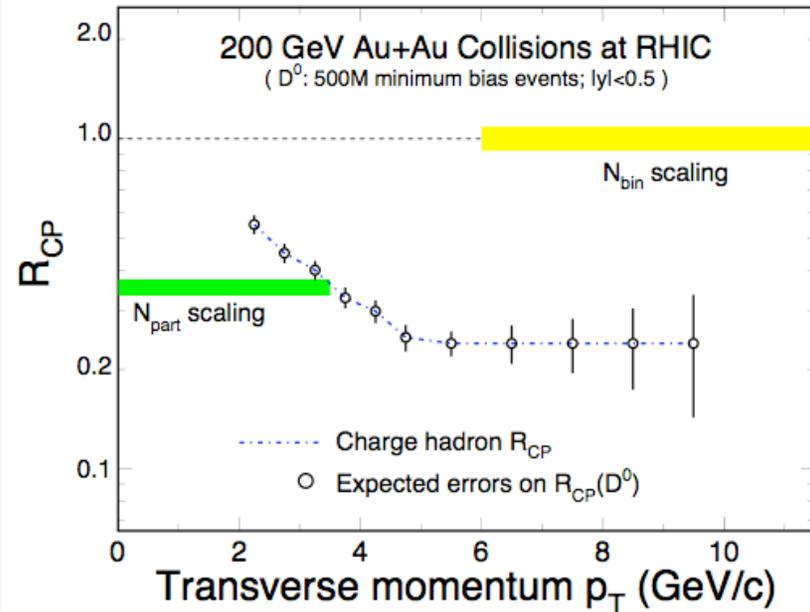
- 1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
 - 2) QCD mass: Chiral symmetry breaking. (constituent quark mass)
- ⇒ New mass scale compared to the excitation of the system.
- ⇒ Important tool for studying properties of the hot/dense medium at RHIC.
- ⇒ Test pQCD predictions at RHIC.

Charm Hadron v_2 and R_{AA}



- 200 GeV Au+Au m.b. collisions (500M events).
- Charm hadron collectivity \Rightarrow drag/diffusion constants \Rightarrow

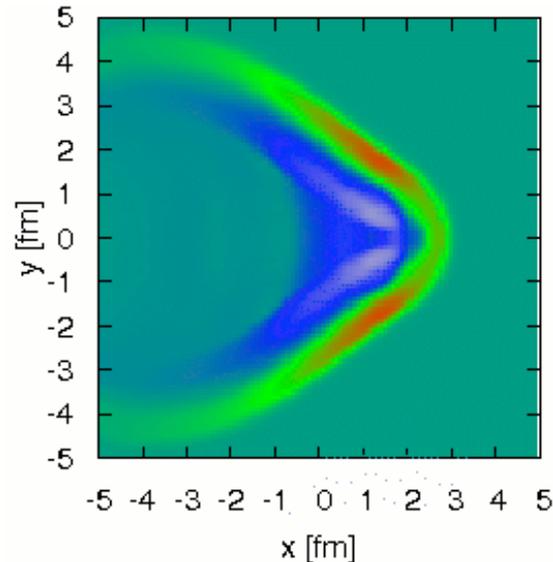
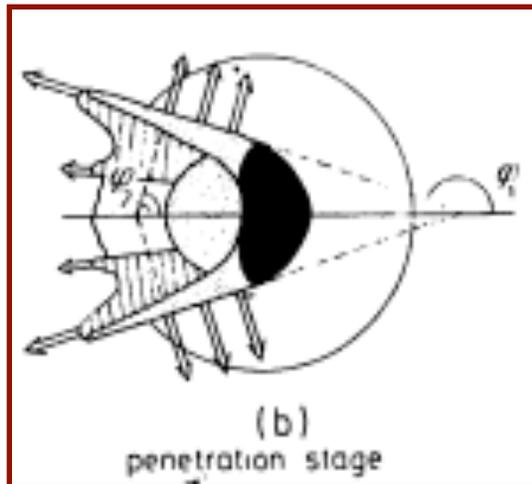
Medium properties!



- 200 GeV Au+Au m.b. collisions ($|y| < 0.5$ 500M events)
- Charm hadron $R_{AA} \Rightarrow$

- Energy loss mechanism!
- QCD in dense medium!

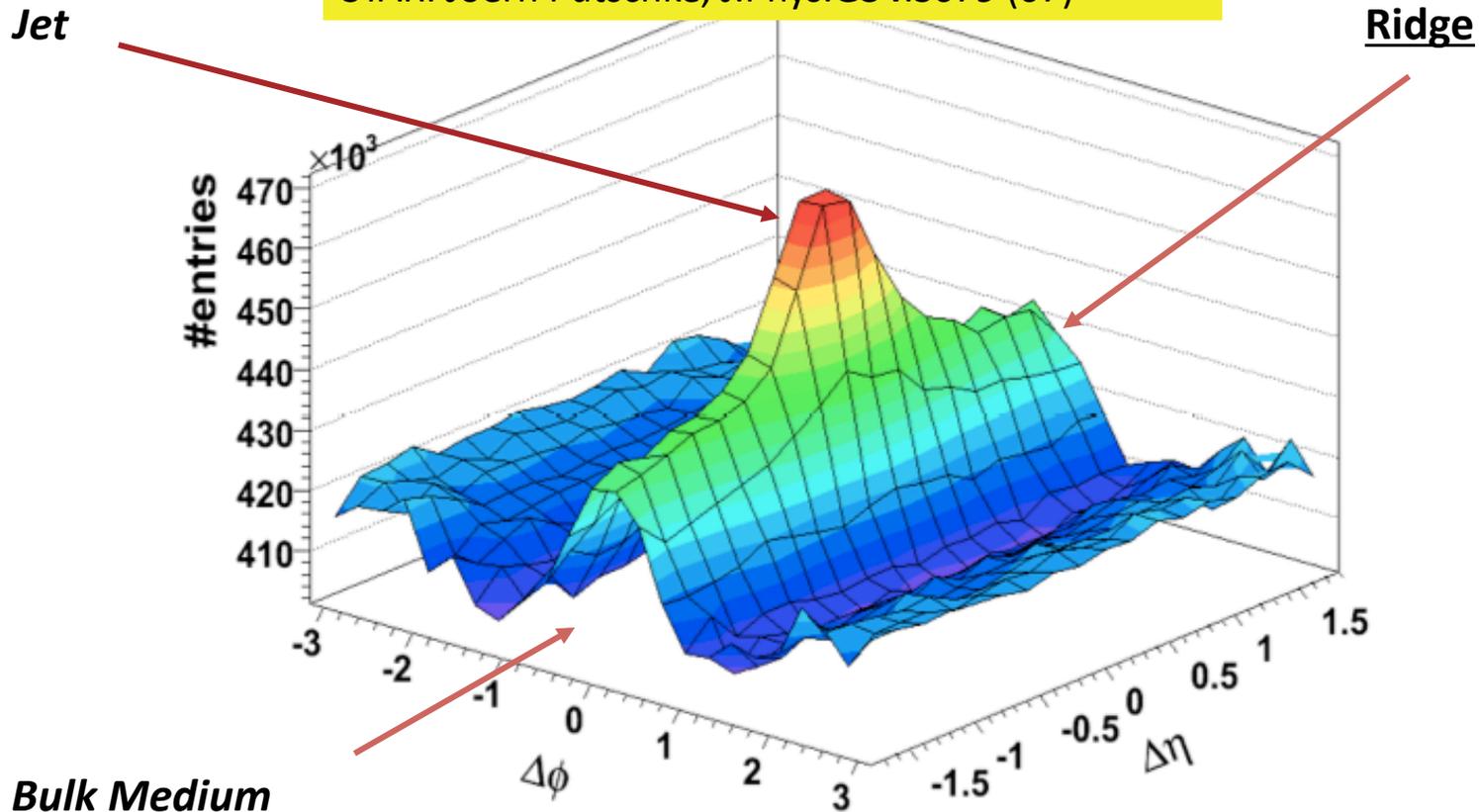
Mach-Cone



- **Mach shock waves:** J. Hofmann, H. Stocker, U. Heinz, W. Scheid, W. Greiner
Phys. Rev. Lett., **36**, (76)
- In high-energy nuclear collisions, a useful tool to analyze the interaction between energetic jets and hot/dense medium in order to extract the properties of the medium.
- **Model predictions:** hydrodynamic, QCD, transport, Ads/CFT

The Ridge from RHIC

STAR: Joern Putschke, J.Phys.G34:S679 (07)



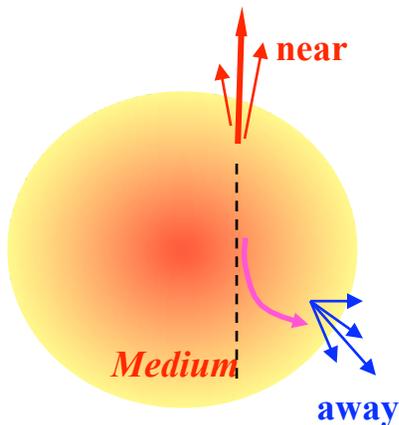
Rich underlying physics: initial condition, jet, bulk, jet-medium interaction, medium responses,... "theoretical responses" are very strong!

N. Armesto et al.; R. Hwa; A. Majumder, et al.; E. Suryak; S. Voloshin; C.Y. Wong

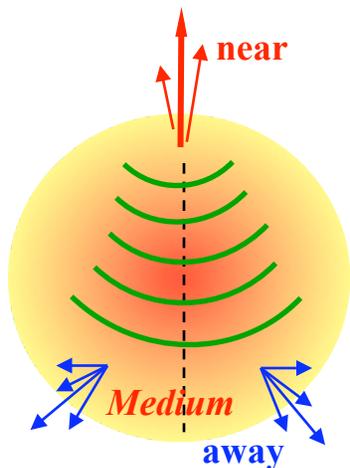
Search for Mach Cone

with Three Particle Correlations

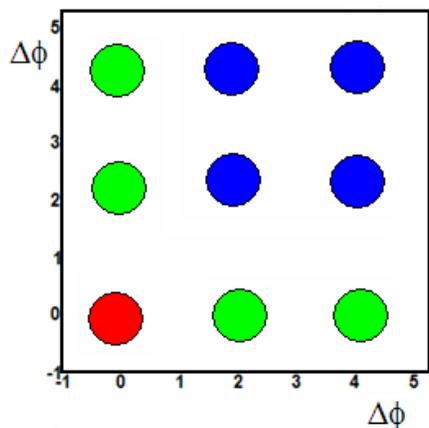
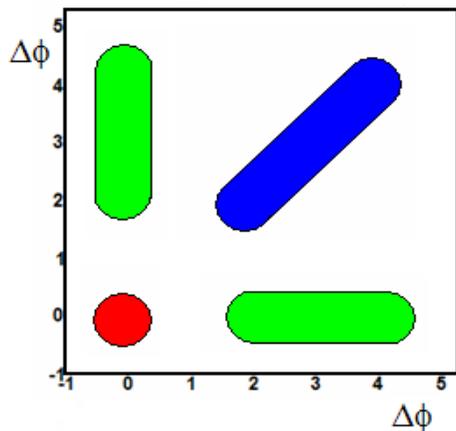
STAR: sub. to PRL, arXiv: 0805.0622



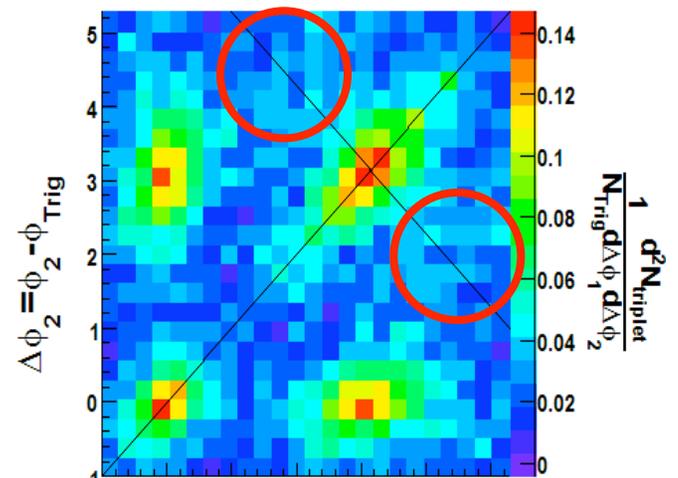
deflected jets



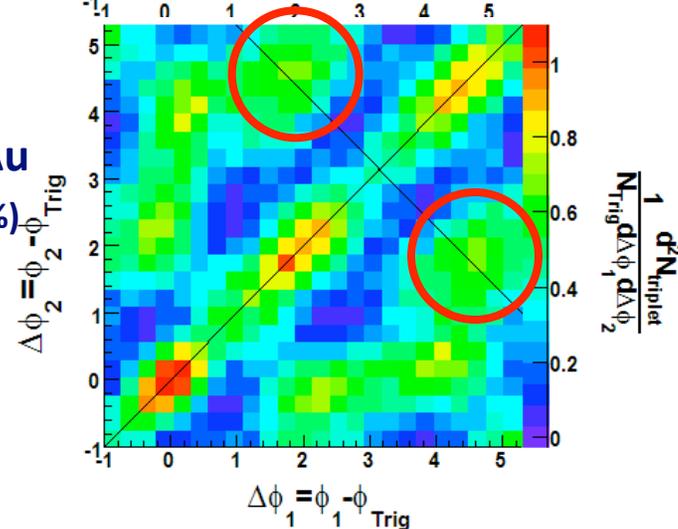
Conical Emission



d+Au



Au+Au
(0-12%)



$$\cos \vartheta^{Mach} = \sqrt{p/\varepsilon}$$

“Evidence of conical emission ...”



sQGP and the QCD Phase Diagram

In 200 GeV Au+Au collisions at RHIC, strongly interacting matter formed:

- Jet energy loss: R_{AA}
- Strong collectivity: v_0, v_1, v_2
- Hadronization via coalescence: n_q -scaling

Questions:

Is thermalization reached at RHIC?

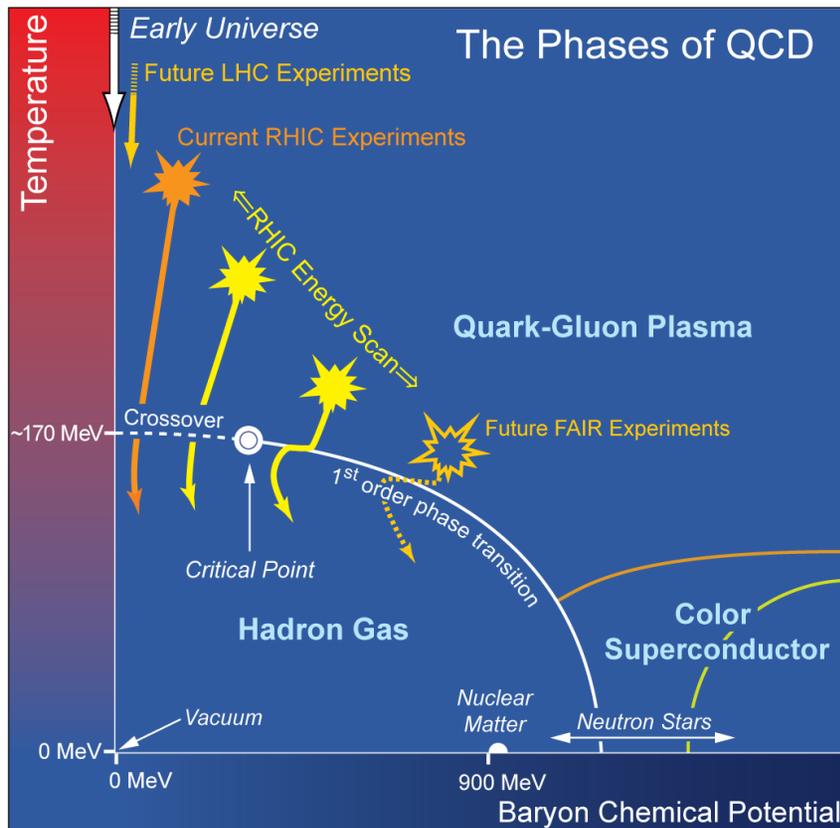
- Systematic analysis with dN/dp_T and dv_2/dp_T results...
- Heavy quark measurements

When (at which energy) does this transition happen?

What does the QCD phase diagram look like?

- RHIC Beam Energy Scan

The QCD Phase Diagram



STAR's plan:

run10: RHIC Beam Energy Scan
run11: Heavy Quark measurements

- LGT prediction on the transition Temperature, T_C , is robust.

- LGT calculation, universality, and Models point to the existence of the critical point on the QCD phase diagram* at finite baryon chemical potential.

- Experimental evidence for either the critical point or 1st order transition is important for our knowledge of the QCD phase diagram*.

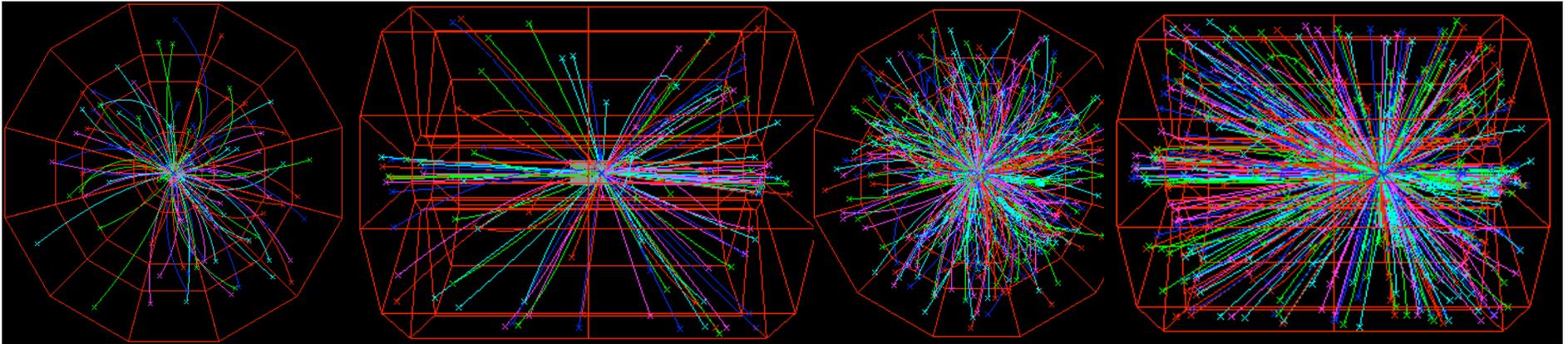
* **Thermalization is assumed**

Stephanov, Rajagopal, and Shuryak, *PRL* **81**, 4816(98)

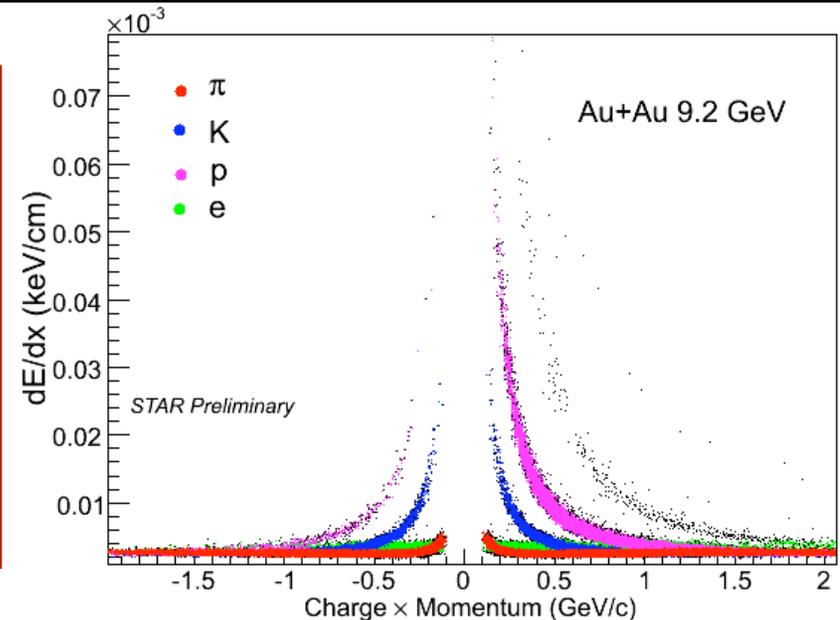
Rajagopal, *PR* **D61**, 105017 (00)

<http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf>

Au + Au Collisions at 9.2 GeV



- 1) ~ 3500 collisions collected
- 2) Determine Luminosity
- 3) STAR has preliminary results on:
Particle identification in TPC; charged multiplicity, π - π interferometry, particle spectra and ratios; v_1 and v_2



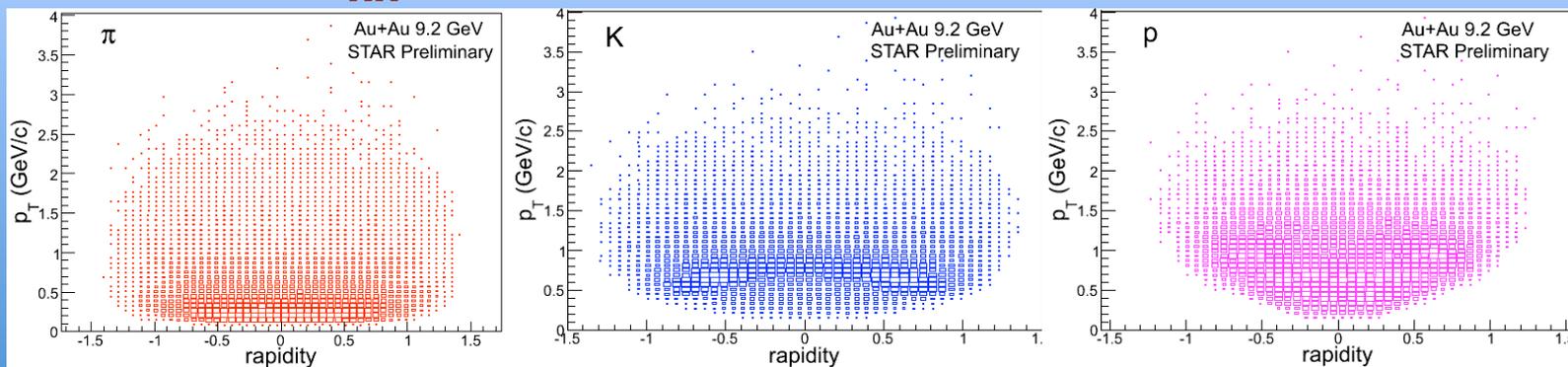
PID will be further significantly extended using full TOF.

Lokesh SQM08

Collider Acceptance

Collider Mode STAR

$\sqrt{s_{NN}} = 9.2 \text{ GeV Au+Au Collisions at RHIC}$

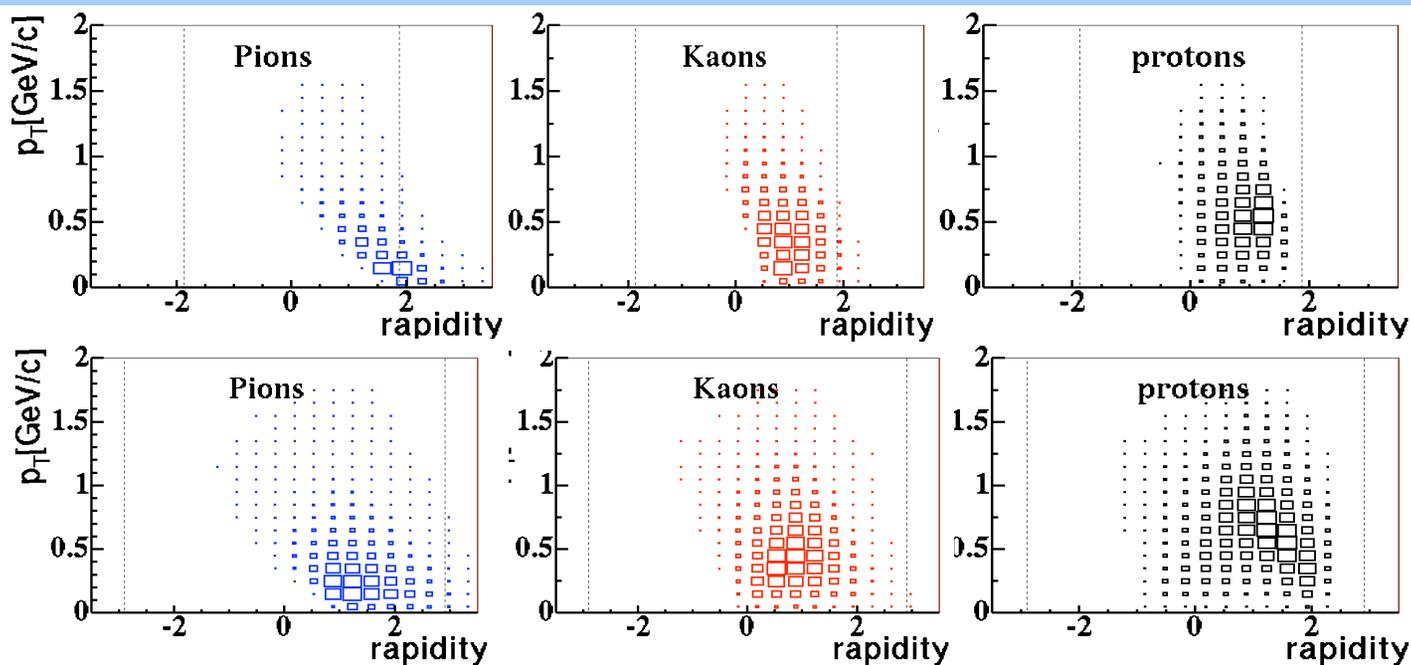


Fix-target Mode NA49

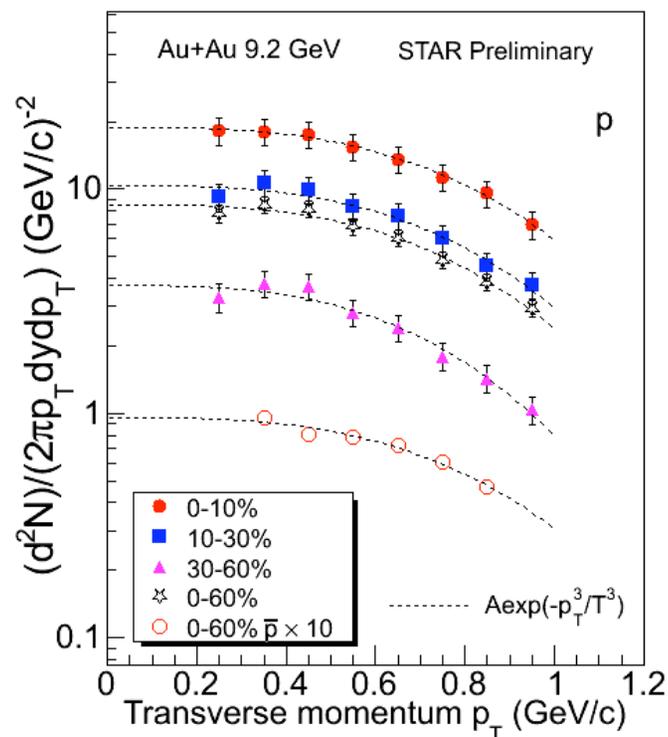
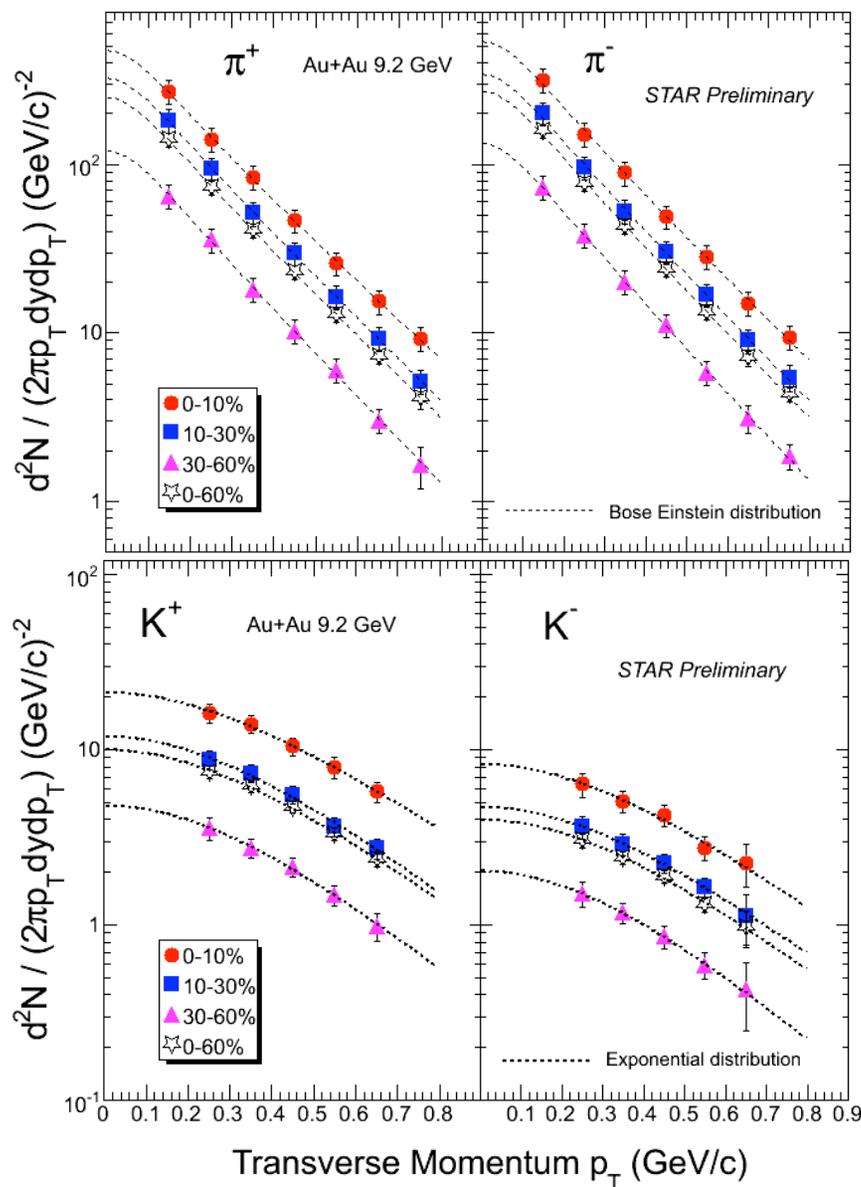
$\sqrt{s_{NN}}$

6 GeV

17 GeV

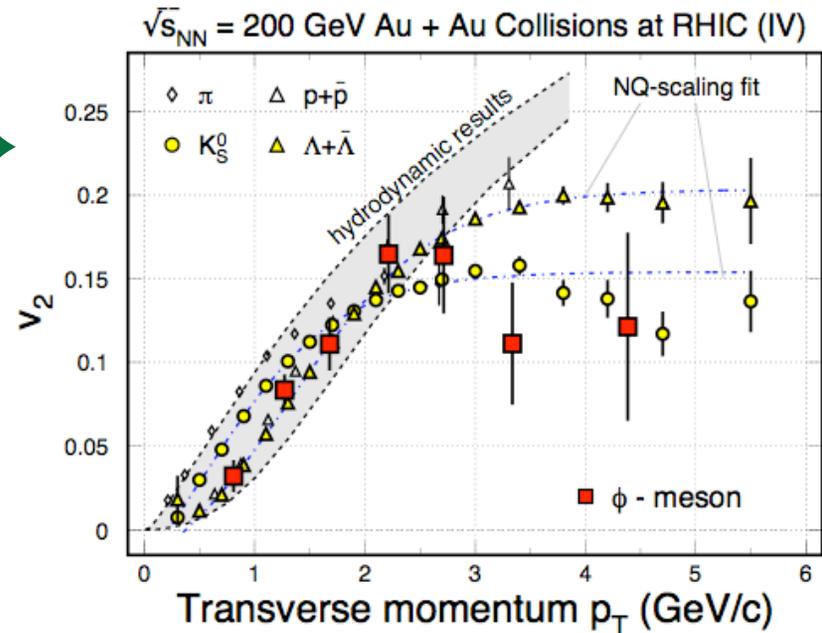
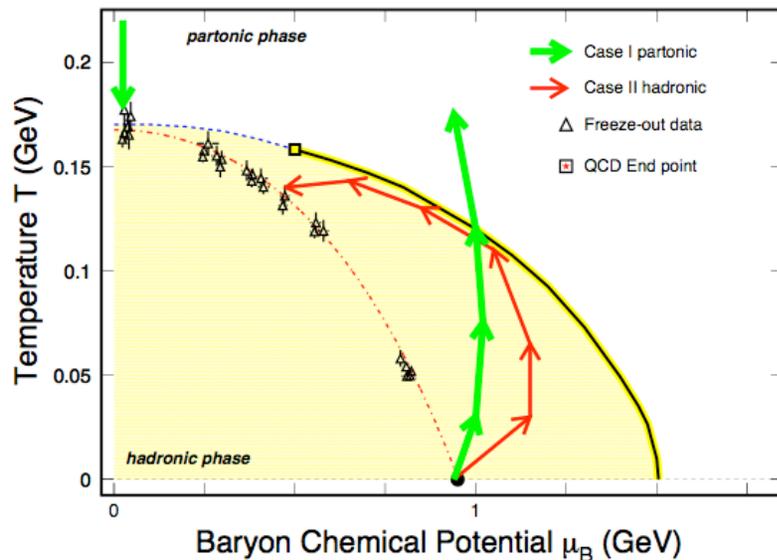


Identified Hadron Spectra at mid-y

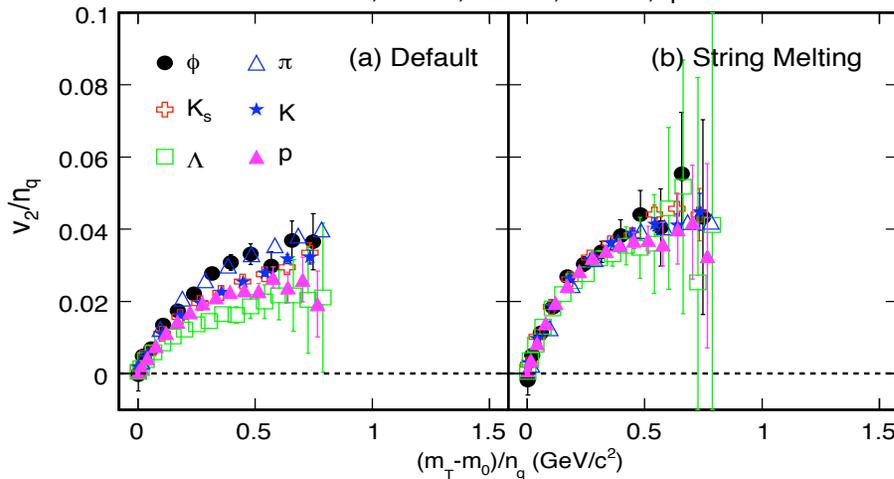


Lokesh Kumar
 STAR: SQM2008

Observable I: Quark Scaling



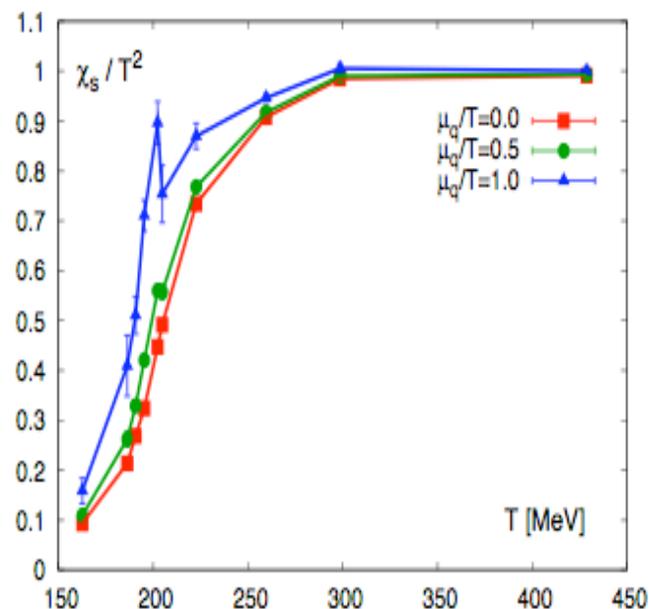
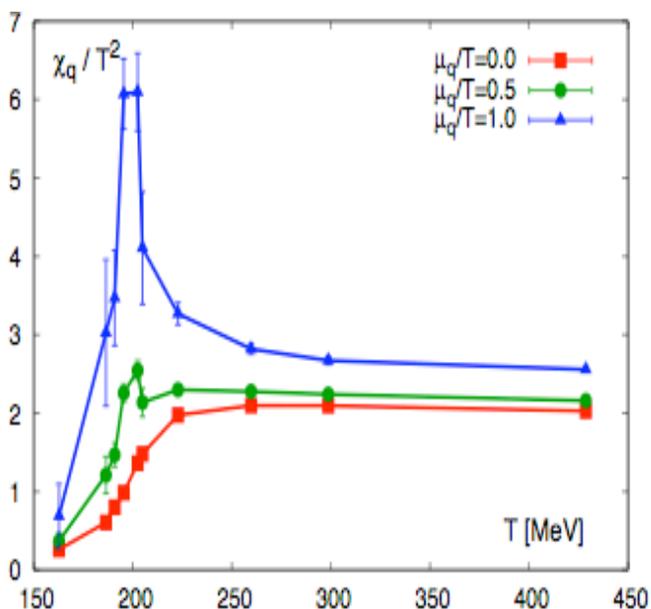
AMPT, Au+Au, 9.2GeV, $b < 14\text{fm}$, $|\eta| < 1$



- $m_\phi \sim m_p \sim 1 \text{ GeV}$
- $ss \Rightarrow \phi \text{ not } K^+K^- \Rightarrow \phi$
- $\sigma_{\phi h} \ll \sigma_{p\pi, \pi\pi}$

In the hadronic case, no number of quark scaling and the value of v_2 of ϕ will be small.

Observable II: χ_q, χ_s



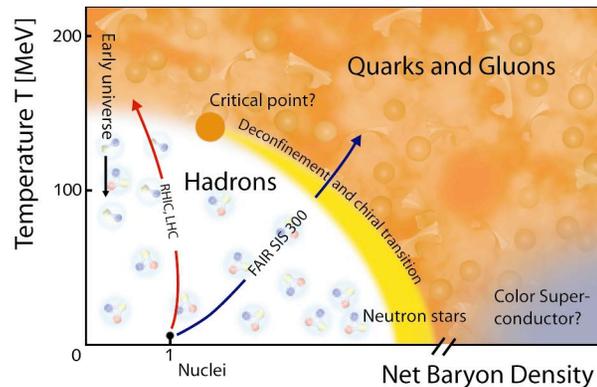
Event by event:

1. net-proton Kurtosis $K_p(E)$
2. two proton correlation functions $C_2(E)$
3. ratio of the d/p
4. ratio of K/p

$$K_p = \frac{\langle N_p^4 \rangle - 3\langle N_p^2 \rangle^2}{\langle N_p^2 \rangle}$$

*M. Cheng et al., arXiv:011.1006
F. Karsch, INT, 2008*

STAR Physics Focus



1) Heavy-ion program

- Study *medium properties, EoS*
- pQCD in hot and dense medium

2) Beam energy scan at RHIC

- Search for *critical point*
- Chiral symmetry restoration

(1) Heavy quark v_2 and R_{AA} :

Thermalization and EoS parameters

(2) Beam energy scan:

Search for the QCD phase boundary and the possibly critical point